EXPERIMENT NO. 1

Moisture Content Determination

Object

To determine the moisture content (water content) of a given soil sample.

Theory and applications

A soil is an aggregate of soil particles having a porous structure. The pores may have water and/or air. The pores are also known as voids. If voids are fully filled with water, the soil is called saturated soil and if voids have only air, the soil is called dry.

Moisture content is defined as the ratio of the mass/weight of water to the mass/weight of solids (Fig. 1.1).

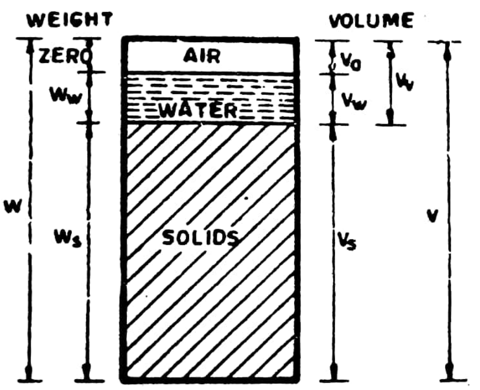


Fig. 1.1 Phase Diagram

$$w = \frac{W_w}{W_s} \tag{1-1}$$

Where w = water content

W_w = mass/weight of water

W_s = mass/weight of solids (mass of oven-dry soil)

The mass of water used in the above expression is the mass of free pore water only. Hence for moisture content determination the soil samples are dried to the temperature at which only pore water is evaporated. This tempereture was standardized 105°C to 110°C. Soils having gypsum are dried at 60°C to 80°C.

The quantity of soil sample needed for the determination of moisture content depends on the gradation and the maximum size of particles. Following quantities are recommended[a].

Soil	*Max. quantity used (gm)*
Coarse gravel	1000 to 2000
Fine gravel	300 to 500
Coarse sand	200
Medium sand	50
Fine sand	25
Silt and clays	10 to 25

The methods to determine moisture content in the laboratory are oven-drying, pycnometer, infrared lamp with torsion balance moisture meter. The approximate methods are alcohal burning method and calcium carbide method.

Applications

Moisture content plays an important role in understanding the behaviour of fine grained soils. It is the moisture content which changes the soils from liquid state to plastic and solid states. Its value controls the shear strength and compressibility of soils. Compaction of soils in the field is also controlled by the quantity of water present. Density of soils are directly influenced by its value and are used in calculating the stability of slopes, bearing capacity of soil-foundation system, earth

(a) Lesser the moisture content, greater the quantity of soil to be taken

pressures behind the retaining walls and pressures due to overburden.

The knowledge of determining the moisture content is helpful in many of the laboratory tests such as Atterberg's limits, shear strength compaction and consolidation.

This experiment may be performed by two different methods..

A. Open drying method

B. Torsion balance moisture content

A—OVEN DRYING METHOD

Apparatus

General

1. Containers (non corrodible, air-tight)
2. Balance (accuracy .04 percent of the weight of the soil taken for test).
3. Oven (interior of non-corroding material, thermostatically controlled).
4. Desiccator.
5. Tongs (one pair).

Procedure

1. Clean, dry and weigh the container with lid.
2. Take the required quantity of the soil specimen in the container and weigh with lid.
3. Maintain the temperature of the oven between 105°C and 110°C for normal soils and 60°C to 80°C for soils having loosely bound hydration water or/and organic matter.
4. Dry the sample in the oven till its mass becomes constant. In normal conditions the sample is kept in the oven for not more than 24 hours.
5. After drying remove the container from the oven, replace the lid and cool in the desiccator.
6. Weigh the dry soil in the container with lid.

Precautions

1. The soil specimen should be loosely placed in the container.
2. Over heating should be avoided.
3. Dry soil sample should not be left in open before weighing.

Observations and Calculations

The moisture content is calculated as follows :

$$w = \frac{W_w}{W_s} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad (1.2)$$

Where W_2 = mass of container with lid+wet soil

W_3 = mass of container with lid+dry soil

W_1 = mass of container with lid

B—TORSION BALANCE MOISTURE METER METHOD

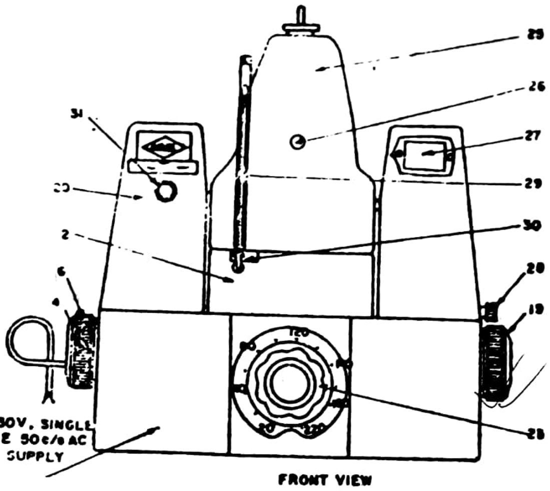
Apparatus

Special

1. Torsion balance moisture meter (0—100% with infrared lamp)
2. Tong

Procedure

1. Set the 100% scale division of the calibrated drum to align with the index mark with the help of drum drive knob (19).
2. With the pan placed on the pivot, check that the pointer is aligned with the index line and the 100% scale division. If not set the pointer with the help of initial setting knob (6).
3. Rotate the drum drive knob anti-clockwise and bring the 0% scale division in line with the index mark, thus prestressing the wire through an amount equal to 100%. (This pre-sets the amount of unbalance. The pointer will now be above the index mark)
4. Raise the lamp housing and carefully distribute the test material evenly on the sample pan until the pointer returns to the index mark. (Approximately 5 grams of the material will be needed in one operation).
5. Lower the lamp housing and switch on the infra-red lamp with the help of the switch provided on the left hand side. Insert the



1.	Base	25.	Lamp housing
2.	Pan house	26.	Lift handle
4.	One off switch	27.	Viewing lens
6.	Initial adjustment knob	28.	Loaking sore
19.	Drum drive knob	29.	Thermometer
23.	Varica knob (for heat control)	30.	Thermometer bracket
24.	Cover	31.	Indicator lamp

Fig. 1.2 Torsion Balance Moisture Meter

thermometer in its socket and bracket. Adjust the variac control knob between 95 and 100 on the scale if it is desired that the temperature of drying should be around 110°C[b] The sample will now begin to loose moisture and the pointer will rise above the index.

6. To determine the percentage reduction of weight at any instant, rotate the drum scale by turning the drum drive knob until the pointer returns to the index Read the percentage directly from the scale. The percent moisture which is read from the scale is the per cent moisture based upon the initial weight of the sample i.e. the wet weight of the sample.

7. The criterion for taking the final reading is that the pointer should remain steady on the index mark which shows that the sample has dried to constant weight. Note the drum scale reading against the pointer which is the percent moisture on the total weight taken. Remove the thermometer from its bracket.

8. For repeating the test use the spare pan so that the pan used first has time to cool and can be cleaned out.

9. Repeat steps 1 to 8 as above with a fresh sample.

Precautions

1. Pan should be cleaned before taking the wet soil in it.
2. For taking the final reading, ensure that pointer should remain constant. It becomes constant normally in 15 to 30 minutes.
3. Temperature should be controlled between 60°C to 80°C for soils having gypsum or/and organic matter. At this temperature pointer becomes constant approximately in 40 to 60 minutes.
4. Instrument should not be subject to any jolting.
5. Do not rotate the initial setting — knob unnecessarily which may lead to snapping.

Observations and Calculations

1. Read the percentage directly from the scale on the drum. This is the moisture content based on the wet mass of the soil.
2. Calculate the moisture content of the soil with respect to dry mass of the soil.

$$w = \frac{m}{(100-m)} \times 100 \qquad (1\text{-}3)$$

Where w = moisture content based on dry mass (%)

m = moisture content based on wet weight, (%)

(b) Keep watch on the column of mercury on the thermometer and when the thermometer records a temperature of 105°C, control the variac in such a manner that there is more rise in the temperature beyond 110°C and the temperature in the housing is maintained at 110°C ± 50°C. If for a particular sample, the temperature is to be higher or lower than 110°C, the variac control knob can be adjusted accordingly.

MOISTURE CONTENT DETERMINATION

EXPERIMENT NO. 1

MOISTURE CONTENT DETERMINATION

OBSERVATIONS AND CALCULATIONS

Soil sample No. **TABLE 1** Date

(Oven Drying Method)

Determination No.	1	2	3
(1) Container No.			
(2) Mass of container with lid. W_1 (gm)			
(3) Mass of container with lid + wet soil W_2 (gm)			
(4) Mass of container with lid + dry soil, W_3, (gm)			
(5) Mass of water, $W_w = W_2 - W_3$ (gm)			
(6) Mass of dry soil, $W_s = W_3 - W_1$ (gm)			
(7) Moisture content, $w = W_2 - W_3 / W_3 - W_1 \times 100$, (%)			

Result

Average Moisture Content, w (%)

Grain Size Analysis - Mechanical Method

Object

To classify the coarse grained soils.

Theory and Applications

Soils having particles larger than 0.075 mm size are termed as coarse grained soils. In these soils more than 50% of the total material by mass is larger than 75 micron. Coarse grained soil may have boulder, cobble, gravel and sand.

Coarse grained soils may have rounded to angular bulky, hard, rock particles with the following sizes :

Boulder-more than 300 mm dia.

Cobble - smaller than 300 mm and larger than 80 mm dia.

Gravel (G) - smaller than 80 mm and larger than 4.75 mm

Coarse gravel - 80 mm to 20 mm

Fine gravel - 20 mm to 4.75 mm

Sand (S) smaller than 4.75 mm and larger than 0.075 mm

Coarse : 4.75 mm to 2 mm

Medium : 2.0 mm to 425 micron

Fine : 425 micron to 75 micron

Name of the soil is given depending upon the maximum percentage of the above components.

Soils having less than 5% particles of size smaller than 0.075 mm are designed by the symbols :

GW — Well graded gravel

GP — Poorly graded gravel

SW — Well graded sand

SP — Poorly graded sand

Soils having greater than 12% of particles of size smaller than 0.075 mm are designated by the following symbols :

GM or GC : Silty gravel or clayey sand

SM or SC : Silty sand or clayey sand

Dual symbols are used for the soils having 75 micron passing between 5 to 12%.

Dry sieve analysis is performed for cohesionless soils if fines are less than 5%.

Wet sieve analysis is done if fines are more than 5% and of cohesive in nature.

Gravels and sands may be either poorly graded (uniformly graded) or well graded depending upon the value of coefficient of curvature and uniformity coefficient.

Coefficient of curvature may be estimated as :

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \qquad (2\text{-}1)$$

D_{60} = diameter at 60% finer

D_{30} = diameter at 30% finer

D_{10} = diameter at 10% finer

It should lie between 1 and 3 for well graded gravels and sands.

Uniformity coefficient

$$C_u = \frac{D_{60}}{D_{10}} \qquad (2\text{-}2)$$

Its value should be more than 4 for well-graded gravels and more than 6 for well graded sands. (I.S : 1498 - 1970).

Applications

The percentage of different sizes of soil particles coarser than 75μ is determined. Coarse grained soils are classified mainly by sieve analysis. The grain size distribution curve gives an idea regarding the gradation of the soil i.e. it is possible to identify whether a soil is well graded or poorly graded. In mechanical soil stabilization, the main principle is to mix a few selected soils in such a proportion

that a desired grain size distribution is obtained for the design mix. Hence for proportioning the selected soils, the grain size distribution of each soil is to be first known.

Apparatus

Special :

1. Ist set sieves of sizes 300 mm, 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm.
2. 2nd set of sieves of sizes 2 mm, 850 μ, 425 μ, 150 μ and 75 micron.
3. Sodium hexametaphosphate (for cohesive soils)
4. Mechanical shaker (optional)
5. Brush
6. Rubber Pestle and Motor

General :

1. Balances (One of accuracy = 1.0 gm, other of accuracy = 0.1 gm.)
2. Weights and weight box
3. Oven
4. Desiccator
5. Drying crucibles
6. Tray/bucket
7. Water

Procedure

1. Take suitable quantity of oven-dry soil depending upon the maximum size of material present in.

TABLE 2.1

Substantial quantities in the soil

Maximum size of material present in substantial quantities	*Quantity to be taken kg*
80 mm	60.0
20 mm	6.5
4.75 mm to 75 micron	0.5

2. (a) If soil seems to have more than 5% of cohesive soils, the soil taken in step (1) is spread out in the large tray or bucket and covered with water. Two grams of sodiumhexa metaphosphate per litre of water used is then be added to the soil. The mix is thoroughly stirred and left for soaking.

(b) The soaked soil specimen is washed on 75 micron I. S. sieve until the water passing the sieve is clean.

(c) The fraction retained on sieve is tipped without loss of material in a tray, dried in the oven at 105° to 110°C and weighed.

(d) Loss in mass will give percentage passing 75 micron sieve.

Sieving for coarser than 4.75 mm size

3. Clean the Ist set of sieves and pan with brush

4. Sieve the soil first through I.S. sieves of first set i.e. 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm manually or using a mechanical shaker for 5-10 minutes.

5. Weigh the material retained on each sieve to 1.0 gm.

Sieving for soil passing from 4.75 mm size

6. Clean the sieve and pan with brush and weigh to 0.1 gm.

7. Sieve the soil through 2nd set of sieves i.e., 2 mm, 850 μ, 425 μ, 150 μ and 75 micron using a mechanical shaker for 10 minutes.

8. Weigh to 0.1 gm each sieve and pan with soil retained on them. The sum of the retained soil mass is checked against the origial mass of soil taken.

Precautions

1. While drying, the temperature of the oven should not be more than 105°C because higher temperature may cause some permanent change in the—75 micron materials.

2. During shaking, soil sample should not be allowed to come out.

3. In wet analysis, all cohesive soil adhering to large size particles should be removed by water.

4. For plotting, per cent finer should be etermined with respect to the total soil taken for iitial analysis.

bservations and Calculations

1. All observations are entered in prescribed bservation tables. Most of the calculations are one in the observation tables itself. In table 1 ie cumulative mass of soil fraction retained on ach sieve is calculated. The cumulative ercentage of soil fraction retained on each sieve calculated on the basis of the total weight of the ample taken for this analysis. Percentage finer calculated by subtracting the percentage retained rom 100.

2. In observation table 2 the cumulative mass f soil fraction retained on each sieve is calculated. he cumulative percentage of soil fraction retained n each sieve is calculated on the basis of the mass f the sample passing 4 75 mm I.S. sieve. The ombined gradation on the basis of the total soil ample taken for analysis is then calculated.

3. Diameter (mm) is taken on log scale and ercent finer on ordinary scale for plotting the rain size distribution curve. Use recommended raph paper.

4. Read the diameters corresponding to 60%, 0% and 10% finer. Calculate coefficient of urvature and uniformity coefficient.

5. Read also the percentage of each soil from he graph paper.

Determination No.	1	2	3
D_{60}			
D_{30}			
D_{10}			
C_c			
C_u			

QUESTIONS

1. What is the purpose of sieve analysis ?
2. Why do you classify the soils ?
3. What are the coarse grained and fine grained soils as per Indian Standard classification of soils for general engineering purposes ?
4. How do you classify the soils by sieve analysis ? Can you classify all types of soils by sieve analysis ?
5. What is coefficient of curvature (C_c) ? Where is it used ?
6. What is coefficient of uniformity (C_u) ? How do you determine it ? What are its applications ?
7. What do you understand by well graded, and uniformly graded soils ?
8. What do you understand by dry and wet sieve analysis ? Which one did you perform ? Why ?
9. What is the grain size distribution curve ? Why do you use a semi-log graph paper for plotting it ?
10. Draw the grain size distribution curves for poorly graded, well graded and uniformly graded soils.
11. What do you understand by GW, GP, GM, GC, SW, SP, SM, SC, SW—SM, GP—SC ? What are the maximum and minimum percentages of fines in these soils ?
12. Classify the soil with the following test data

(i)	Gravel	15%
(ii)	Sand	75%
(iii)	Fines	10%
(iv)	C_u	9
(v)	C_c	1.2

13. What are the applications of the results of sieve analysis in field problems ?
14. What are the number of the sieves which you are using ? What do you understand by these number ?

15.
16.
17

15. What is the difference between Indian Standard and U.S. Standard numbers ?

16. How much soil did you take for sieve analysis ? What are the considerations to fix the quantity of soil to be taken for sieve analysis ?

17 What is the accuracy of the balance used in this test ? What is the basis of selecting this accuracy of the balances in sieve analysis ?

18. How do you calculate percentage finer and percentage fines ? Where are these used ?

19. What type of soil sample do you need for sieve analysis ? Why ?

20. What are the main sources of errors and precautions in sieve analysis ?

DISCUSSIONS

EXPERIMENT No. 2

GRAIN SIZE ANALYSIS - MECHANICAL METHOD
OBSERVATIONS AND CALCULATIONS

Soil Sample No. **TABLE 1** Date

(Soil coarser than 4.75 mm)

Mass of total soil sample taken for analysis, kg =

Sieve No.	Sieve opening (mm)	mass of sieve (gm)	mass of Sieve + Soil (gm)	mass of soil retained (4)—(3) (gm)	Cumulative mass of soil retained (gm)	Cumulative % of soil retained (%)	% finer (passing) 100—(7)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
80 mm								
40 mm								
20 mm								
10 mm								
4.75 mm								
Pan								

Soil Sample No. **TABLE 2** Date

(Soil passing from 4.75 mm Sieve and retained on 75 Micron Sieve)

(i) Mass of total soil sample taken for analysis, kg =

(ii) % of soil sample passing from 4.75 mm sieve =

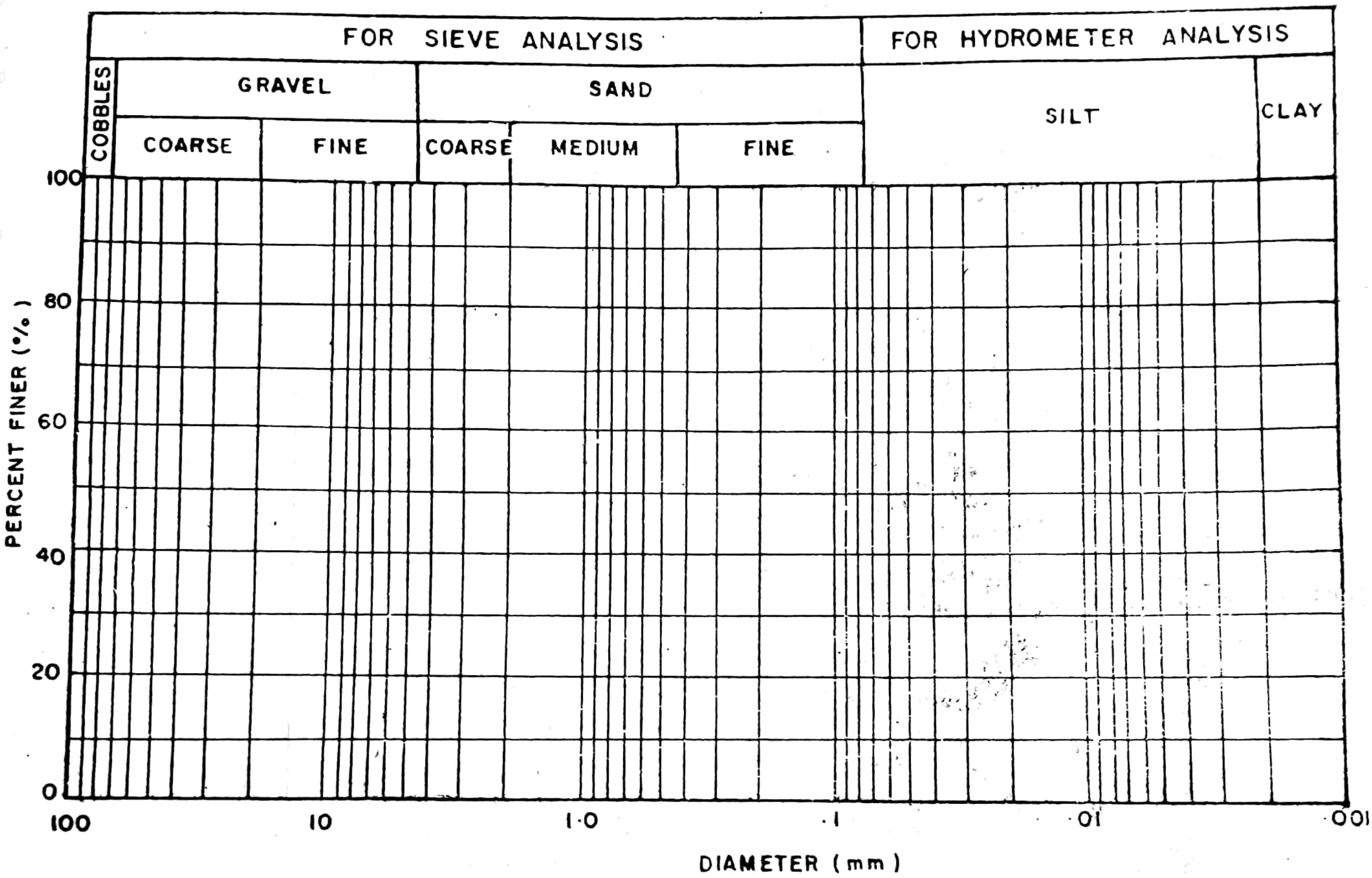
(iii) Mass of soil sample taken for this analysis kg =

Sieve No.	Sieve opening (mm)	Mass of Sieve (gm)	Mass of Sieve + Soil (gm)	Mass of soil retained (4)—(3)	Cumulative Mass of Soil retained	Cumulative % of soil retained	% finer w.r.t. 4.75 mm passing	Combined % finer w.r.t. total soil sample (8)×(ii)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2 mm								
850 micron								
425 micron								
150 micron								
75 micron								
Pan								

EXPERIMENT No. 2 & 3

GRAIN SIZE ANALYSIS

Soil Sample No. Graph Sheet (Semilog) Date



Results

Boulder + Cobble, % =

Gravel, % =

Sand, % =

Silt or clay, % =

Classification =

Liquid and Plastic Limit Tests

Object

(a) To determine liquid limit
(b) To determine plastic limit
(c) To classify the soil
(d) To find flow index
(e) To find toughness index

Theory and Applications

Liquid limit is the water content at which soil passes from zero strength to an infinitesimal strength, hence the true value of liquid limit can not be determined. For determination purpose liquid limit is that water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 1.25 cm under an impact of 25 blows in a standard liquid limit apparatus. The soil at the water content has some strength which is about 0.17 N/cm^2 (17.6 g/cm^2). At this water content soil just passes from liquid state to plastic state.

The moisture content at which soil has the smallest plasticity is called the plastic limit. Just after plastic limit the soil displays the properties of a semi-solid. Change in state at these limits are shown in Fig. 4.1.

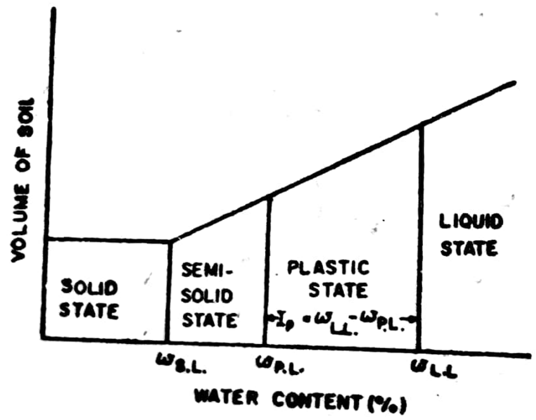


Fig. 4.1 Relationship between Volume of Soil and its Moisture Content.

For determination purpose, the plastic limit is defined as the water content at which a soil will just begin to crumble when rolled into a thread of 3 mm in diameter.

The difference in moisture contents or interval between the liquid and plastic limits is termed the plasticity index. Knowing the liquid limit and plasticity index, soil may be classified with the help of plasticity chart according to Indian Standard on soil classification (IS 1498-1970), Fig. 4.2.

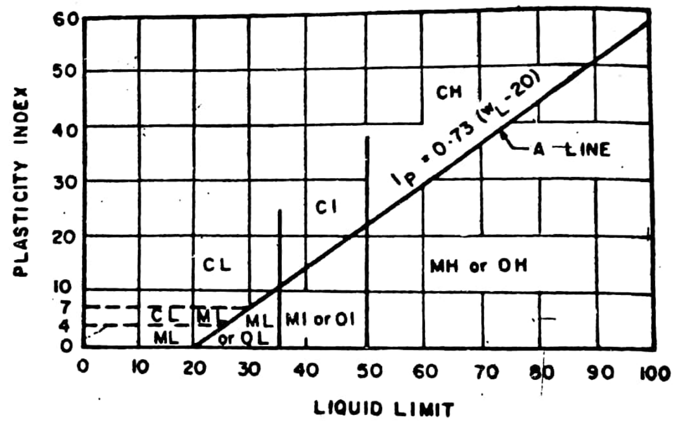


Fig. 4.2 Plasticity Chart (I.S.)

In the plasticity chart following symbols are used :

CL = Clay of low compressibility
CI = Clay of medium compressibility
CH = Clay of high compressibility
ML = Silt of low compressibility
MI = Silt of medium compressibility
MH = Silt of high compressibility
OL = Organic soil of low compressibility
OI = Organic soil of medium compressibility
OH = Organic soil of high compressibility

Applications

The values of liquid limit and plastic limit are directly used for classifying the fine grained cohesive

soils according to Indian Standard on soil classification. Once the soil is classified, it helps a lot in understanding the behaviour of soils and selecting the suitable methods of design, construction and maintenance of the structures made up or/and resting on soils.

The values of these limits are also used in calculating the flow index, toughness index, and relative plasticity index which are useful in giving an idea about the plasticity, cohesiveness, compressibility, shear strength, permeability, consistency and state of cohesive soils. Atterberg (1911) shows the correlations between the plasticity index, soil type, degree of plasticity and degree of cohesiveness.

Plasticity index	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non cohesive
<7	Silt	Low-plastic	Partly cohesive
7—17	Silt clay	Med. plastic	Cohesive
> 17	Clay	High plastic	Cohesive

Apparatus

Special

1. Casagrande liquid limit device
2. A.S.T.M. and B.S. grooving tool (Casagrande type)
3. Glass plate 20 × 15 cm
4. 425 micron I.S. sieve
5. 3 mm diameter rod.

General

1. Spatula 2. Basin (300 c.c. capacity) 3. Balance (0.01 gm sensitivity) 4. Water content tins or crucibles 5. Drying oven 6. Distilled water 7. Measuring cylinder 8. Desiccator

Procedure

(a) Liquid Limit :

1. Adjust the cup of the liquid limit apparatus with the help of grooving tool gauge and the adjustment plate to give a drop of exactly 1 cm on the point of contact on base.

2. Take about 120 gm of an air-dried sample passing 425 micron sieve.

3. Mix it thoroughly with some distilled water to form a uniform paste.

4. Place a portion of the paste in the cup of the liquid limit device, smooth the surface with spatula to a maximum depth of 1 cm. Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.

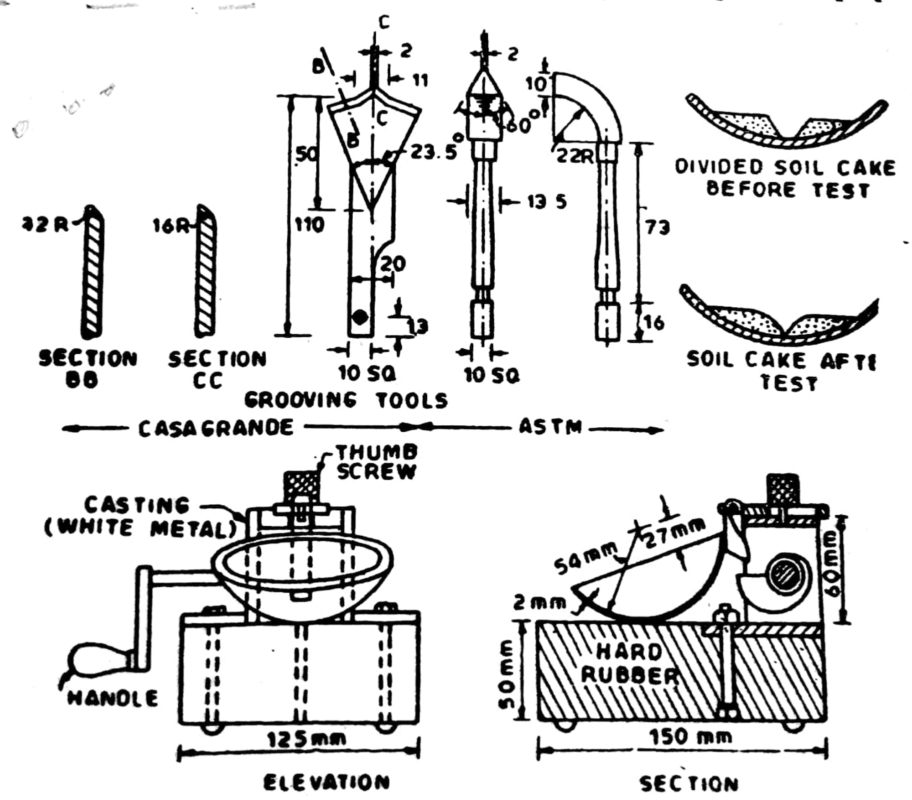


Fig. 4.3 Apparatus with Dimensions for Liquid Limit Test

5. Turn the handle at a rate of 2 revolutions per second and count blows until the two parts of the soil sample come into contact at the bottom of the groove along a distance of 10 mm.

6. Transfer about 15 gm of the soil forming the edges of the groove that flowed together to a water content tin, and determine the water content by oven drying.

7. Transfer the remaining soil in the cup to the main soil sample in the basin and mix thoroughly after adding a small amount of water[a].

8. Repeat steps 4, 5 and 6. Obtain at least four sets of readings in the range of 10 to 40 blows.

(b) Plastic Limit :

1. Take about 30 gm of air dried sample passing 425 micron sieve.

2. Mix thoroughly with distilled water on the glass plate until it is plastic enough to be shaped into a small ball.

3. Take about 10 gm of the plastic soil mass and roll it between the hand and the glass plate to form the soil mass into a thread. If diameter of thread becomes less than 3 mm without cracks, it shows that water added in the soil is more than its plastic limit, hence the soil is kneaded further and rolled into thread again.

4. Repeat this rolling and remoulding process until the thread starts just crumpling at a diameter of 3 mm.

5. If crumpling starts before 3 mm diameter thread in step 3, it shows that water added in step 2 is less than the plastic limit of the soil, hence some more water should be added and mixed to a uniform mass and rolled again, until the thread starts just crumpling at a diameter of 3 mm.

6. Collect the pieces of crumbled soil thread at 3 mm diameter in an air tight container and determine moisture content.

7. Repeat this procedure twice more with fresh samples of 10 gm each.

Precautions

1. Use distilled water in order to minimise the possibility of iron exchange between the soil and any impurities in the water.

2. Soil used for liquid and plastic limit determinations should not be oven dried prior to testing.

3. In liquid limit test, the groove should be closed by a flow of the soil and not by slippage between the soil and the cup.

4. After mixing distilled water to the soil sample, sufficient time should be given to permeate the water throughout the soil mass.

5. Wet soil taken in the container for moisture content determination should not be left open in the air even for some time, the containers with soil samples should either be placed in desiccator or immediately be weighed.

6. For each test, cup and grooving tool, should be clean.

Observations and Calculations

(a) Liquid Limit (L.L. or $w_{L.L.}$)

1. Use table 1 for recording the number of blows and calculating the moisture contents.

2. Use semilog graph paper, take number of blows on semilog scale (x-axis and water contents on ordinary scale (y-axis). Plot all the points and draw a straight line (flow curve) passing through these points.

3. Read the water content at 25 blows which is the value of liquid limit.

(b) Plastic limit (P.L. or $w_{P.L.}$)

Use table 2 for calculating the plastic limit.

(c) Classification of soil.

1. Calculate plasticity index (P.I. or I_p)

$$I_p = w_{L.L.} - w_{P.L.} \tag{4-1}$$

2. Use plasticity chart for classification of given soil.

or

Calculate the plasticity index of 'A' line

$$(P.I.)_A = 0.73\,(w_{L.L.} - 20) \tag{4-2}$$

(a) It is found convenient to start with soil drier than the liquid limit and obtain values by increasing the water content.

where $w_{L.L.}$ is in percentage

If P.I. > (P.I.)$_A$ the soil is clay

If P.I. < (P.I.)$_A$ the soil is silt

L.L. = 0—35 low compressibility

35—50 medium compressibility

> 50 high compressibility

(d) Flow Index (F.I. or I_F)

1. Extend the flow curve at both ends so as to intersect the ordinates corresponding to 10 and 100 blows.

2. Read the water contents at 10 and 100 blows. Difference of these two water contents is equal to flow index.

or

The flow index may be calculated from the eq.

$$I_F = \frac{w_1 - w_2}{\log_{10} \frac{N_2}{N_1}} \qquad (4\text{-}3)$$

w_1 = water content in % at N_1 blows

w_2 = water content in % at N_2 blows

(e) Toughness Index (T.I. or I_T)

$$\text{Tougness Index } I_T = \frac{\text{Plasticity Index}}{\text{Flow Index}} = \frac{I_P}{I_F}$$

QUESTIONS ON LIQUID LIMIT

1. What do you understand by liquid limit ?
2. How do you define liquid limit to determine it in the laboratory ?
3. It is possible to determine the true value of liquid limit ?
4. What is the shear strength of soil at liquid limit, determined by you ?
5. Two clays obtained from two different pites have different values of liquid limit. Are the shear strength values at liquid limit different or the same ?
6. What is consistency of soil at liquid limit ?
7. What is the state of soil at liquid limit ?
8. What changes in soil properties do take place at liquid limit ?
9. Is liquid limit of a soil a natural or conventional soil index ?
10. What is the relationship between liquid limit and natural water content of the soil ?
11. Why the liquid limits of 2 samples obtained from two sites are different ?
12. Why may the liquid limits of 2 samples obtained from the same site be different ?
13. If there are two soils A and B, whose liquid limits are 60% and 40% and natural moisture content of both the soils is 30%. In which soil do you expect more shear strength and settlement at their liquid limits and natural moisture contents ?
14. In question 13 which soil does have more permeability ?
15. In question 13 if plastic limit of both the soils is 20 what are the corresponding consistency at their natural moisture contents ?
16. What are the practical uses of liquid limit ?
17. Who developed this liquid limit apparatus ?
18. Is there any other apparatus to determine liquid limit ? If yes, who developed that apparatus ? What are its relative merits and demerits over that ?
19. If the height of cup, speed of cup, type of water given in the standard procedure are not truely followed, what effect do you expect on the value of liquid limit ?
20. Are you using undisturbed sample or remoulded sample ? Why ?
21. If oven dry sample is used instead of air dried sample as mentioned in the procedure, what is the effect on the value of liquid limit ?
22. Why semi-log graph paper is used to estimate the value of liquid limit ?
23. What do you understand by flow curve and flow index ? What do you interprete from these values ?
24. If you have only one set of reading between 20 and 30 blows, can you estimate fairly accurate value of liquid limit ?

QUESTIONS ON PLASTIC LIMIT

1. What is understood by plastic limit ?
2. Is it possible to get the true value of plastic limit ?

3. How the plastic limit is defined to determine it in the laboratory ?
4. What is plastic state ? What is the state of soil at plastic limit ? Do different soils at their plastic limits have the same state ?
5. What is the consistency of soil at plastic limit ? Do different soil at their plastic limits have different consistencies ?
6. Is plastic limit a natural or conventional soil index ?
7. Why are the plastic limits of the samples obtained from two sites different ?
8. Why may the plastic limits of two sample obtained from the same site be different ?
9. Can plastic limit of a soil be more than its liquid limit or/and natural moisture content ? Explain.
10. What is the degree of saturation at plastic limit ?
11. What happens when water content of a soil is reduced from liquid limit to plastic limit ?
12. Do different soils have the same shear strength at their plastic limits. Justify.
13 What is plasticity index ? Compare two soils of different plasticity index but having same liquid limit with respect to dry strength, toughness, permeability, rate of volume change, cohesivness and degree of plasticity.
14. What are relative plasticity index, liquidity index, consistency index and water plasticity ratio ?
15. There are two soils with the following values :

Soil	*Liquid Lt.* (%)	*Plastic Lt.* (%)	*Natural moisture content* (%)
A	70	30	40
B	55	25	40

i) Find out the plasticity index, relative plasticity index.

(ii) Classify both the soils from plasticity chart.

(iii) Compare their shear strength at their liquid limit, plastic limit and natural moisture content.

(iv) Compare the compressibility of the two soils at their liquid limit, plastic limit and natural moisture contents.

(v) Compare change in volume from liquid limits to natural moisture content and plastic limit in the two cases.

(vi) Compare with respect to cohesiveness, permeability, dry strength, toughness and degree of plasticity.

(vii) Note states and consistencies of both the soils at natural moisture contents.

16. What are the practical applications of plastic limit, plasticity index and relative plasticity index of soil ?
17. What type of samples are used to determine the plastic limit i.e. undisturbed or remoulded ? Why ?
18. How does oven dry soil sample affect the value of plastic limit ?
19. Why do you use soil passing from 425 μ sieve to determine the plastic limit while its value is used to classify only the fine grained soils, which is a passing from 75 μ sieve ?
20. What is the effect of soils between 425 μ and 75 μ on the plastic limit ?
21. Why the distilled water is used to determine the plastic limit ? If natural water is having some impurities, would you like to use distilled water or natural water ?
22. What is size of thread you are making to determine the plastic limit ? Why ?
23. If a thread of 5 mm is made instead of 3 mm, what is the effect on plastic limit ?

DISCUSSIONS

EXPERIMENT No. 4

LIQUID AND PLASTIC LIMITS
OBSERVATIONS AND CALCULATIONS

TABLE 1

Soil Sample No. Liquid Limit Date

Determination No.	1	2	3	4	5
(1) No. of blows					
(2) Container No.					
(3) Mass of container + wet soil, (gm.)					
(4) Mass of container + dry soil, (gm.)					
(5) Mass of water (3)—(4), (gm.)					
(6) Mass of container, (gm.)					
(7) Mass of dry soil (4)—(6), (gm.)					
(8) Moisture content (5)/(7) × 100, (%)					

TABLE 2

Soil Sample No. Plastic Limit Date

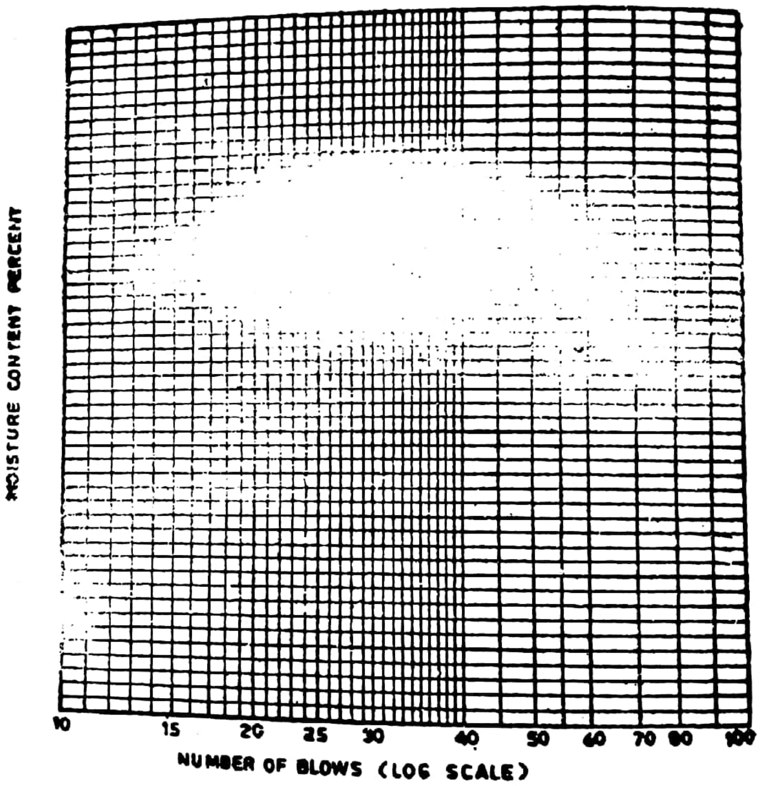
Determination No.	1	2	3
(1) Container No.			
(2) Mass of container + wet soil, (gm.)			
(3) Mass of container + dry soil, (gm.)			
(4) Mass of water, (2) — (3), (gm.)			
(5) Mass of container, (gm.)			
(6) Mass of dry soil, (3) — (5), (gm.)			
(7) Plastic limit, (4/6) × 100, %			

Average Plastic limit =

EXPERIMENT No. 4
LIQUID LIMIT
OBSERVATIONS AND CALCULATIONS
TABLE 3
(Semi Log Graph Paper)

Soil Sample No. Date

Flow Curve



Liquid Limit = Moisture Content at 25 Blows

(From the Graph)

Results

Liquid limit L.L. (%) =
Plastic limit P.L. (%) =
Plasticity Index P.I. =
Classification =
Flow Index I_F =
Toughness Index I_T =

EXPERIMENT NO. 6

Specific Gravity Test

Object

To determine the specific gravity of the soil particles passing 4.75 mm I. S. Sieve using pycnometer.

Theory and Applications

Specific gravity is the ratio of the mass/weight in air of a given volume of dry soil solids to the mass/weight of equal volume of distilled water at 4°C.

In Fig. 6-1 let (a) represent the empty pynometer of mass $= W_1$

(b) represent the pycnometer + soil grains of mass $= W_2$

(c) represent the pycnometer + soil grains + water of mass $= W_3$

(d) represents the pycnometer + water of mass $= W_4$

$\therefore$ Mass of soil grains $W_s = W_2 - W_1$

Mass of equal volume of distilled water

$= (W_4 + W_2 - W_1 - W_3)$

Specific gravity of soil grains

$$= \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \qquad (6\text{-}1\ A)$$

$$= \frac{W_s}{W_s + W_4 - W_3} \qquad (6\text{-}1\ B)$$

The value of specific gravity depends upon temperature, hence its value is reported at standard temperature of 27°C.

$$G_s \text{ (at } 27°C) = G_s \text{ (at } T_t°C) + \frac{\text{Specific gravity of water at } T_t°C}{\text{Specific gravity of water at } 27°C} \qquad (6\text{-}2)$$

Applications

Specific gravity of soil grains is a important property and is used in calculating void ratio, porosity, degree of saturation if density and water content are known.

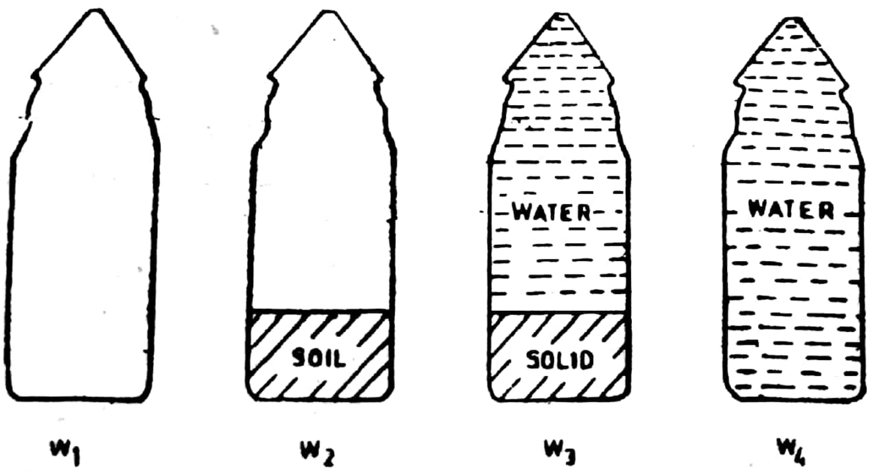
$$\text{Void ratio, } e = \frac{G_s(1 + w_w)}{v_t} v_w - 1 \qquad (6\text{-}3)$$

Where e = void ratio

G_s = specific gravity

w_w = water content

v_w = mass density of water (g/cc)



(a) (b) (c) (d)

Fig. 6.1 Specific Gravity Determination by Pycnometer

γ_t = moist density of soil (g/cc)

and degree of saturation, $S = \frac{G_s \times W}{e} \times 100$ (6-4

Where S = degree of structure (%)

G_s = specific gravity of soil grains

w = water content

e = void ratio

Its value helps upto some extent in identification and classification of soils. It gives an idea about the suitability of the soil as a construction material, higher value of specific gravity gives more strength for roads and foundations. It is used in computing the soil particle size by means of hydrometer analysis. It is also used in estimating the critical hydraulic gradient in soil when a sand boiling condition is being studied and in zero air-void calculations in the compaction theory of soils.

Its value ranges as follows :

Coarse grained soils	2.6—2.7
Fine grained soil	2 7—2 8
Organic soil	2.3—2.5

Apparatus

Special

1. Pycnometer
2. 4.75 mm (or 2 mm) I.S. Sieve

General

1. Vacuum pump (or hot water bath)
2. Balance (accuracy 0.1 gm)
3. Drying oven
4. Desiccator
5. Glass rod
6. Distilled and deaired water
7. Thermometer (0 to 50°C)

Procedure

1. Dry the pycnometer thoroughly and weigh with its cap tightly screwed on.
2. Mark the cap and pycnometer with a vertical line parallel to the axis of the pycnometer so that each time the cap is screwed the same amount.
3. Unscrew the cap and put in about 200 gm of oven dried soil[a] passing 4.75 mm I.S. Sieve[b] and weigh again.
4. Add sufficient deaired water to cover the soil about half full and screw on the cap.
5. Shake well and connect to the vacuum pump to remove entrapped air.
6. Allow the air to be evacuated for at least 20 minutes for fine grained soil or 10 minutes for sandy soils. Shake the pycnometer occasionally to assist in the air evacuation.
7. After the entrapped air has been largely removed, disconnect the pump and fill the pycnometer with water about three fourth full.
8. Reapply the vaccum for at least 5 minutes. Evacuation should be continued until very few bubbles appear on the top of the water.
9. After the air has been eliminated, fill the pycnometer with water completely upto the mark.
10. Thoroughly dry the pycnometer from the outside and weigh it.
11. Record the temperature of the content in degree centigrade.
12. Clean the pycnometer by washing water thoroughly.
13. Fill the pycnometer with water upto its top and screw on the cap.
14. Weigh the pycnometer after drying it on the outside thoroughly.
15. Repeat the test twice more.

Notes (a) Specimens containing natural moisture may also be taken, but oven dry mass or the soil must be determined at the end of test.

(b) (i) 4.75 mm sieve is used to determine specific gravity of sand silty or clayey soil.

(ii) 2 mm sieve is used if the value of specific gravity is used in connection with hydrometer analysis.

Precautions

1. The soil grains whose specific gravity is to be determined should be completely dry.

2. Dried soil taken for testing should have the soil grains of its original size, so if on drying soil humps are formed, they should be broken to its original size.

3. Hold the rubber tubing tightly with the pycnometer so that there is no leakage when vacuum pump works.

4. Inaccuracies in weighing and failure to completely eliminate the entrapped air are the main sources of error. Both should be avoided by careful working.

5. Cap should be screwed upto the same mark during the test.

6. Cap should be properly screwed with washer to avoid any leakage.

Observations and Calculations

(a) Determine the specific gravity of soil grains using equation (6-1 A).

$$(G_s) = \frac{(W_2-W_1)}{(W_2-W_1)-(W_3-W_4)}$$

(b) Calculate the correction factor C_t.

$$(C_t) = \frac{\text{Relative density of water at } T_t{}^\circ C}{\text{Relative density of water at } 27^\circ C}$$

(c) Calculate the specific gravity at 27°C

$$(G_s)_{27^\circ C} = (G_s)_{T_t} \times C_t$$

(d) The average of three values of the same soil sample is taken and reported to the nearest 0.01. If any of the values differs by more than 0.03 from the average, that test is discarded and other test is done.

QUESTIONS

1. What do you understand by specific gravity of soil grains ?

2. What is the difference between the specific gravity of soil grains and soils ?

3. Derive an expression for specific gravity of soil grains for laboratory determination.

4. What are normal ranges of specific gravity for gravel, sand, silt, clay and organic soils ?

5. What are the relationships between void ratio, degree of saturation and specific gravity of soil grains ?

6. How do you calculate the critical gradient with the help of specific gravity value ?

7. What is the effect of temperature on the specific gravity ?

8. What is the standard temperature at which the value of specific gravity is determined ?

9. How and where does the specific gravity value help in studying the consolidation properties of clays ?

10. What is the difference between density of soil and specific gravity of soil grains ?

11. What are the units of density and specific gravity of soil grains in MKS system of unit ?

12. How do you use the value of specific gravity in knowing the size of soil grains by hydrometer analysis.

13. What is the relationship between dry density of soil at zero air voids, specific gravity of soil grains and water content ?

14. What are the field applications of specific gravity of soil grains ?

15. Can you use any other liquid instead of water in this test ? If yes, name that liquid.

16. If you use a liquid other than water, what modifications in the expression of specific gravity will be made ?

17. Can you use this test to determine the moisture content of the soils ? Explain.

18. If specific gravity of soil particles retained on 4.75 m.m. I.S. sieve is to be determined, what changes in the procedure do you expect ?

19. During the test, if air is not completely removed, what is the effect on the value of specific gravity ?

20. If soil taken for test is not completely dry, what is the effect on the value of specific gravity ?

21. What precautions do you take during this test.

22. What are the other methods to determine the specific gravity of soil grains ?

DISCUSSIONS

EXPERIMENT No. 6

SPECIFIC GRAVITY

OBSERVATIONS AND CALCULATIONS

Soil Sample No. Date

(i) Test temperature T_t, °C =

(ii) Relative density of water at T_t, °C =

(iii) Relative density of water at 27°C =

(iv) Correction factor due to temp., C_t =

Determination No.	1	2	3
(1) Pycnometer/Bottle No.			
(2) Mass of Pycnometer W_1 (gm)			
(3) Mass of Pycnometer + dry soil, W_2 (gm)			
(4) Mass of Pycnometer + Soil + Water, W_3 (gm)			
(5) Mass of Pycnometer + Water, W_4 (gm)			
(6) Specific gravity of soil at T_t °C			
(7) Specific gravity of soil at 27°C = (6) × C_t			

Results

Specific gravity of soil grains at 27°C =

Compaction Test

Object

1. To determine the optimum moisture content and maximum dry density of a soil by proctor test.
2. To plot the curve of zero air void.

Theory and Applications

Compaction is the process of densification of soil mass by reducing air voids. This process should not be confused with consolidation which is also a process of densification of soil mass but by the expulsion of water under the action of continuously acting static load over a long period.

The degree of compaction of a soil is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. For a given compaction energy every soil attains the maximum dry density at a particular water content which is known as optimum moisture content.

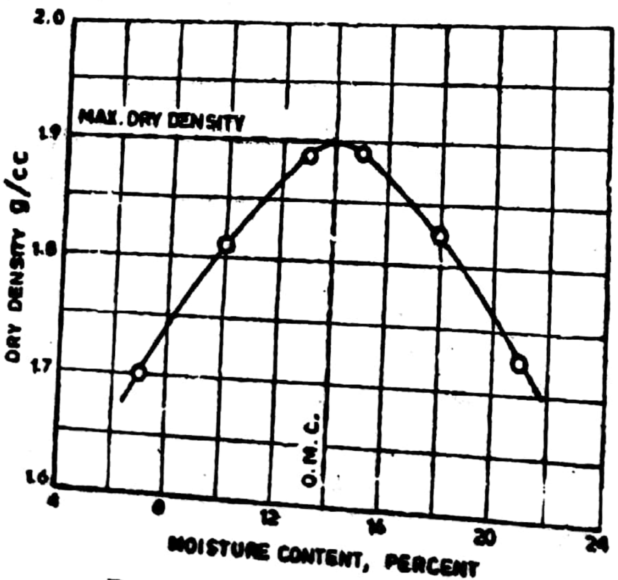


Fig. 8.1 Compaction Curve

In the dry side, water acts as a lubricant and helps in the closer packing of soil grains. In the wet side, water starts to occupy the space of soil grains and hinders in the closer packing of grains.

Application

Compaction of soils increase their density, shear stregth, bearing capacity but reduces their void ratio, porosity, permeability and settlements. The results of this test are useful in the stability of field problems like earthen dams, embankments, roads and airfields. In such constructions, the soils are compacted. The moisture content at which the soils are compacted in the field is controlled by the value of optimum moisture content determined by the laboratory proctor compaction test. The compaction energy to be given by the field compaction unit is also controlled by the maximum dry density determined in the laboratory. In other words, the laboratory compaction tests results are used to write the compaction specification for field compaction of soils.

Apparatus

Special :

1. Cylindrical mould (capacity 1000 c.c., internal dia 100 m.m., effective height 127.3 m.m.)

   or

   Cylindrical mould (capacity 2250 c.c., internal diameter 150m.m. effective height 127.30m.m.)

2. Rammer for light compaction (face diameter 50 m.m., mass of 2.6 kg, free drop 310 m.m.)

   or

   Rammer for heavy compaction (face diameter 50 m.m., mass 4.89 kg, free drop 450 m.m.)

3. Mould accessories (detachable base plate, removable collar).

4. I.S. Sieves (20 mm, 4.75 mm)

General

1. Balance (capacity 10 kg, sensitivity 1 gm)
2. Balance (capacity 200 gm sensitivity .01 gm)
3. Drying oven (temperature 105°C to 11°C)
4. Desiccator
5. Drying crucibles
6. Graduated jars
7. Straight edge
8. Large mixing pan
9. Spatula
10. Scoop

Procedure

1. Take about 20 kg for 1000 cc mould or 45 kg for 2250 cc mould of air dried and mixed soil.

2. Sieve this soil through 20 mm and 4.75 mm sieves.

3. Calculate the percentage retained on 20 mm and 4.75 mm sieves and passing from 4.75 mm sieve. Do not use the soil retained on 20 mm sieve.

4. Use a mould of 10 cm diameter if percentage retained on 4.75 mm sieve is less than 20 or use a mould of 15 cm diameter if percentage retained on 4.75 mm sieve is more than 20.

5. Mix the soil retained on 4.75 mm sieve and passing from 4.75 mm sieve thoroughly in the proportion obtained in step 3.

6. Take about 2.5 kg of the soil for 1000 cc mould or 6 kg for 2250 cc mould for light compaction. Or take about 2.8 kg of the soil for 1000 cc mould or 6.5 kg for 2250 cc mould for heavy compaction.

7. Add water to it to bring its moisture content to about 4% in coarse grained soils and 8% in fine grained soils.

8. Clean, dry and grease lightly the mould and base plate. Weigh the mould with base plate.

9. Fit the collar and place the mould on a solid base.

10. *For light compaction,* compact the wet soil in three equal layers by the rammer of mass 2.6 kg and free fall 31 cm with 25 evenly distributed blows in each layer for 10 cm diameter mould and 56 blows for 15 cm diameter mould. Alternatively *for heavy compaction,* compact the soils using the rammer of mass 4.89 kg and free fall 45 cm in five layers, each layer being given 25 blows for 10 cm diameter mould and 56 blows for 15 cm diameter mould.

11. Remove the collar and trim off the soil flush with the top of the mould. In removing the

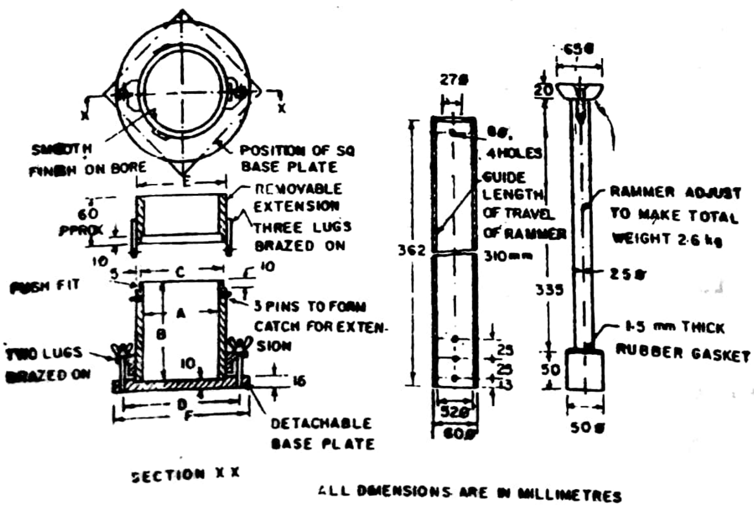


Fig. 8.2 Dimensional Apparatus for compaction

collar rotate it to break the bond between it and the soil before lifting it off the mould.

12. Clean the outside of the mould and base place, weigh the mould with soil and base plate.

13. Remove the soil from the mould and obtain a representative soil sample from the bottom, middle and top for water content determination.

14. Weigh the drying crucible with samples and put in the drying oven at temperature 105°C to 110°C for 24 hours.

15. Repeat the above procedure with 7; 10, 13, 16, 19 and 22% of water contents on coarse grained fresh soil samples and 11, 14, 17, 20 23 and 26% of water contents on fine grained fresh soil samples approximately.

16. Next day, first weigh the crucibles with dry soil samples and then the empty crucibles.

Precautions

1. Adequate period is allowed for mixing the water with soil before compaction.

2. The blows should be uniformly distributed over the surface of each layer.

3. Each layer of compacted soil is scored with a spatula before placing the soil for the succeeding layer.

4. The amount of soil used should be just sufficient to fill the mould i.e. at the end of compacting the last layer the surface of the soil should be slightly (5 mm) above the top rim of the mould.

5. Mould should be placed on a solid foundation during compaction.

Observations and Calculations

1. Enter all observations in table 1 and calculate the wet density.

2. Calculate the dry density by using the equation

$$\gamma_d = \frac{\gamma_t}{1+w} \qquad (8\text{-}1)$$

Where γ_d = dry density (g/cc)

γ_t = wet density (g/cc)

w = water content

3. Plot the water content on x-axis and dry density on y-axis draw the smooth curve, called the compaction curve.

4. Calculate the dry density at 100% saturation.

$$\gamma_d = \frac{G_s \gamma_w}{1+\frac{wG_s}{S}} \qquad (8\text{-}2)$$

G_s = specific gravity of soil grains

w = water content

γ_w = unit mass of water (1 g/cc)

S = degree of saturation (one for fully saturated soils).

5. Plot the 100% saturation or Zero Air Voids curve on the same graph.

6. Read the point of maximum density and water content corresponding to maximum density from compaction curve.

7. Calculate the degree of saturation at optimum moisture content using equation 8-2.

QUESTIONS

1. What is compaction of soils ? Why is it done?

2. Differentiate between compaction and consolidation of soils.

3. What is optimum moisture content ?

4. What is maximum dry density of soil at its O.M.C. ? Does it mean that density can not be more than this for a given soil ?

5. What is meant by dry side and wet side of optimum ? Which side is preferred for field compaction ? Explain.

6. What are methods of laboratory compaction of soils.

7. What are the factors affecting the laboratory compaction ?

8. What are the field methods of compacting the soils ?

9. What are the factors affecting the compaction in the field ?

10. Which laboratory method did you use ? Explain ?

11. What do you understand by field compaction control ?

12. How does laboratory compaction result help in the control of field compaction ?

13. What are the soil properties affected by compaction ?

14. Are the optimum moisture content and dry density constant for one type of soil ?

15. What is zero air void line ? Why is it plotted with compaction curve ?

16. What are field applications of compaction test ?

17. Why is it called Proctor's compaction test ?

18. Differentiate between Proctor compaction and modified Proctor compaction test ?

19. What is size of mould being used by you ?

20. What is energy imparted by Proctor compaction test and modified compaction test ?

21. What is Jodhpur mini compaction test ? Who has developed it ? What are its advantages ?

22. What is the effect of size and shape of mould on optimum moisture content and dry density If energy per unit volume is constant ?

23. What are the approximate values of optimum moisture content and dry density for coarse grained and fine grained soils ?

24. What are the precautions to be taken during this test ? Explain.

DISCUSSIONS

EXPERIMENT No. 8

COMPACTION TEST

OBSERVATIONS AND CALCULATIONS

TABLE 1

Soil Sample No. Date

Soil retained on 20 mm sieve (%) =

Soil retained on 4.75 mm sieve (%) =

Soil passing from 4.75 mm sieve (%) =

Specific gravity of soil grains =

Diameter of mould, d (cm) =

Height of mould, h (cm) =

Volume of mould, V (cm^3) =

Mass of mould, W (gm) =

Type of test =

Wt. of rammer =

No. of layers =

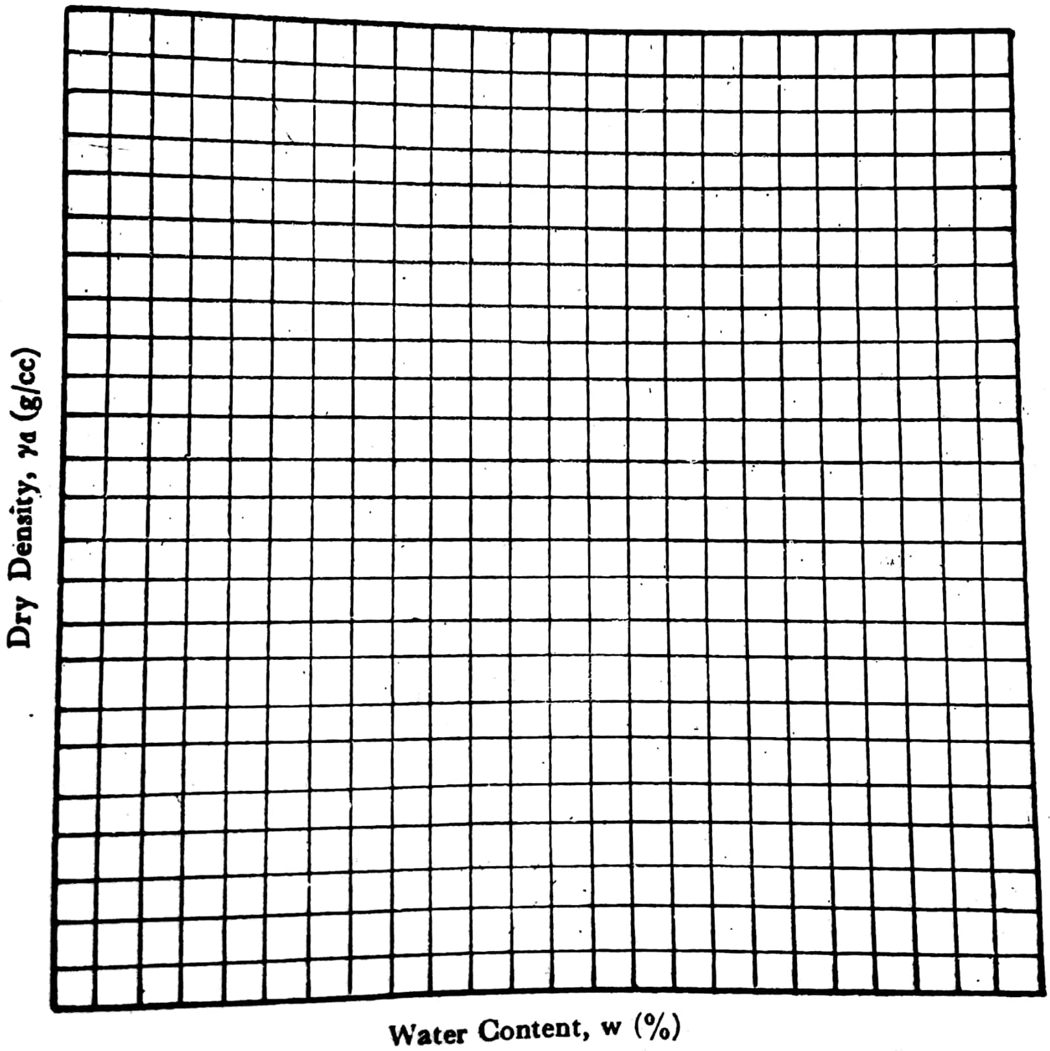
No. of blows/layer =

Determination No.		1	2	3	4	5	6	7
(1) Mass of mould + compacted soil	(gm)							
(2) Mass of compacted soil W_t	(gm)							
(3) Wet density, $\gamma_t = \frac{W_t}{V}$	(g/cc)							
(4) Crucible No.								
(5) Mass of crucible + wet soil,	(gm)							
(6) Mass of crucible + dry, soil,	(gm)							
(7) Mass of water (5) − (6),	(gm)							
(8) Mass of crucible,	(gm)							
(9) Màss of dry soil, (6) − (8)	(gm)							
(10) Water content, w = (7)/(9) × 100	(%)							
(11) Dry density, $\gamma_d = \frac{\gamma_t}{1 + w}$	(g/cc)							
(12) Dry density at 100% saturation	(g/cc)							

EXPERIMENT No. 8

COMPACTION TEST
OBSERVATIONS AND CALCULATIONS

Soil Sample No. **Recommended Graph Sheet** **Date**



Results

Optimum moisture	**(%)**	=
Maximum mass dry density, γ_d	**(g/cc)**	=
Degree of saturation at O.M.C.	**(%)**	=

EXPERIMENT No. 11

In-Place Density Test

Object

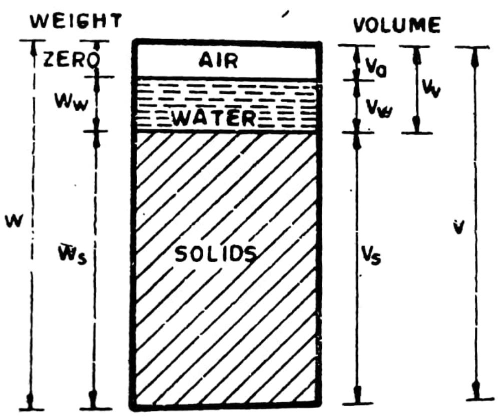
1. To determine the mass density of soils by :
   (a) Core cutter method
   (b) Sand replacement method
2. To estimate void ratio and degree of saturation.

Theory

Density is defined as the mass per unit volume of soil. In Fig. 11.1,

$$\text{density, } \gamma = \frac{W}{V}$$

Where γ = mass density of soil
W = total mass of soil
V = total volume of soil



(The word weight may be replaced by mass)
Fig. 11.1

Here mass and volume of soil comprises the whole soil mass. In the above figure, voids may be filled with both water and air or only air or only water, consequently the soil may be wet or dry or saturated. In soils the mass of air is considered negligible and therefore the saturated density is maximum, dry density is minimum and wet density is in between the two. If soils are found below water table, submerged density is also estimated.

The density can be expressed in g/cm³, or t/m³, or kg/m³, or lb/ft³. For calculating the submerged density, the density of water is taken as 1 g/cm³ = 1 t/m³

Dry density of the soil is calculated by using equation (11-2)

$$\gamma_d = \frac{\gamma_t}{1 + w} \tag{11-2}$$

Where γ_d = dry density of soil
γ_t = wet density of soil
w = moisture content of soil

Density of soils may be determined by core cutter test, sand replacement test, rubber balloon test, water displacement method and gamma ray method. Void ratio (e) is the ratio of volume of voids to volume of soil solids.

Degree of saturation (S) is defined as the ratio of volume of water to the volume of voids. In Figure 11.1,

$$e = \frac{V_v}{V_s} \times 100 \tag{11-3}$$

and

$$S = \frac{V_w}{V_v} \times 100 \tag{11-4}$$

Where e = voids ratio in %
S = degree of saturation in %
V_v = volume of voids
V_s = volume of solids
V_w = volume of water

Further, the following relationships can be obtained from figure 11.1.

$$e = \frac{G_s \gamma_w}{\gamma_d} - 1 \quad (11.5)$$

$$S = \frac{G_s w}{e} \quad (11.6)$$

Where

G_s = specific gravity of soil solids
γ_d = dry density
γ_w = density of water
w = water content

Applications

Density is used in calculating the stress in the soil due to its overburden pressure. It is needed in estimating the bearing capacity of soil foundation system, settlement of footings, earth pressures behind the retaining walls, dams, embankments. Stability of natural slopes, dam, embankments and cutsis checked with the help of density of those soils It is the density which controls the field compaction of soils. Permeability of soils depends upon its density. Relative density of cohesionless soils is determined by knowing the dry density of that soil in natural, loosest and densest states. Void ratio, porosity and degree of saturation need the help of density of soils.

In this chapter the following two methods are discussed to determine the field density of soils.

A. Core cutter method
B. Sand replacement method

A. Core Cutter Method

Apparatus

Special :

1. Cylindrical core cutter (height = 12.74 cm, dia 10 cm)
2. Steel rammer
3. Steel dolley (2.5 cm high and 10 cm internal diameter).

General :

1. Balance (accuracy 1 gm)
2. Balance (accuracy .01 gm)
3. Steel rule
4. Spade or pickaxe
5. Straight edge
6. Knife
7. Water content crucibles
8. Desiccator
9. Oven
10. Tongs

Procedure

1. Measure the height and internal diameter of the core cutter.
2. Weigh the clean core cutter.
3. Clean and level the place where density is to be determined.
4. Press the cylindrical cutter into the soil to its full depth with the help of steel rammer.
5. Remove the soil round the cutter by the spade.
6. Lift up the cutter
7. Trim the top and bottom surfaces of the sample carefully.
8. Clean the outside surface of the cutter.
9. Weigh the core cutter with soil.
10. Remove the soil core from the cutter and take representative sample in the crucibles to determine the moisture content.

Precautions

1. Steel dolly should be placed on the top of the cutter before ramming it down.
2. Core cutter should not be used in gravels and boulders.
3. Before lifting the cutter, soil should be removed round the cutter to minimise the disturbances.
4. While lifting the cutter, no soil should drop down.
5. During pressing and lifting the cutter, care should be taken that some soil is projected at both the ends of the cutter.
6. Values should be reported to second place of decimal.

Observations and Calculations

1. Enter all observations in table 1,
2. Calculate wet dnsity of soil.

$$\gamma_t = \frac{W_2 - W_1}{V}$$

Where

W_2 = mass of cutter + soil
W_1 = mass of cutter only
V = volume of cutter

3. Calculate dry density, void raio and degree of saturation using equations 11.2, 11.5 and 11 6 respectively.

B. Sand Replacement Methoa

Apparatus

Special

1. Sand pouring cylinder
2. Trowel or bent spoon
3. Cylindrical calibrating container
4. Metal tray with hole (30 cm square with 10 cm hole in the centre)
5. Sand (clean oven dried, passing 600 micron sieve)

General

1. Balance (accuracy 1 gm)
2. Balance (accuracy .01 gm)
3. Moisture content crucibles
4. Oven
5. Desiccator
6. Tongs
7. Glass plate (about 45 cm square)
8. Metal tray (about 30 cm square)
9. Scraper tool
10. Measuring jar (1000 cc)

Procedurs

Calibration of Apparatus

1. Measure the internal volume of the calibrating container from the volume of the water required to fill the container.
2. Fill the pouring cylinder with sand withir about 1.0 cm of the top and weigh it.
3. Place the pouring cylinder concentrically on the top of the calibrating container.
4. Open the shutter to allow the sand to run out and fill the calibrating cylinder.
5. When there is no further movement of sand in the pouring cylinder, close the shutter.
6. Remove the pouring cylinder and weigh it to the nearest gram.
7. Place the pouring cylinder on a plane surface such as the glass plate.
8. Open the shutter and allow the sand to run out. When there is no movement of sand in the cylinder, close the shutter.
9. Weigh the pouring cylinder with remaining sand.

Measurement of Soil Density

1. Clean and level the ground where the field density is required.
2. Fill the pouring cylinder with dry sana within about 1.0 cm of the top and weigh it.
3. Place the metal tray with the central hole over the portion of soil to be tested.
4. Excavate the soil approximately 10 cm dia at 15 cm deep with bent spoon. The hole in the tray will guide the diameter of the hole to be made in the soil.
5. Collect the excavated soil in the metal tray weigh it to the nearest gram.
6. Determine moisture content of the excavated soil.
7. Place the pouring cylinder over the hole so that base of the cylinder covers the hole concentrically.
8. Open the shutter and allow the sand to run out into the hole. When there is no movement of sand, the shutter is closed.
9. Remove the cylinder and weigh it.

Precautions

1. If for any reason it is necessary to excavate the holes to depth other than 15 cm, the calibrating cylinder should be replaced by one of the depth which is the same as the hole to be excavated.
2. Case should be taken in excavating the hole to tnat it is not enlarged by levering the dibber against the side of the hole, as this will result in lower density being recorded.
3. No loose material should be left in the hole.
4. Initial height of sand in the pouring cylinder should be kept same during calibration and density determinations.

5. There should be no vibrations during this test.
6. Since dry density of soils varies from point to point, it is necessary to repeat the test at several points and to average the result.

Observations and Calculations

1. Enter all the readings in table 2, 3 and 4.
2. Bulk density of sand is calculated as shown in table 2. This density is used in determining the volume of the hole made in the soil.
3. Table 4 shows the calculations of wet density, dry density, void ratio and degree of saturation of the soil.
4. Equations 11.2, 11.5 and 11.6 are used to calculate the dry density, void ratio and degree of saturation respectively.

QUESTIONS

1. Draw the phase diagram for a wet soil.
2. Define dry, wet and saturated densities of the soil.
3. What do you understand by submerged density ? Explain.
4. Mention the field conditions under which different types of densities have to be used.
5. Out of these various types of densities, which one of them is maximum and minimum ? Explain.
6. What are the units of density ?
7. What are the main factors affecting the value of density of soil ? Explain.
8. If you know wet density of a soil, how do you calculate its dry, saturated and submerged densities ?
9. Which density is used in determining the relative density of cohesionless soil ? Explain.
10. Differentiate between density, relative density and specific gravity of a soil.
11. What are the field problems where density is used ?
12. Define void ratio and degree of saturation.
13. Besides density what other properties do you need to calculate void ratio and degree of saturation of soils ?
14. What are the methods to determine in-place (or insitu or field) density of soils ?
15. Compare core cutter and sand replacement methods to determine the field density.
16. How do you determine the field density of soils by rubber balloon method ?
17. What is the effect of *inserting* the core cutter in the soils on the density of soils ?
18. What are the precautions to be taken in cutter method ?
19. What are the precautions to be taken in sand replacement method ?
20. Why do you take the same quantity of sand in the pouring cylinder during calibration and density determination ?
21. Why do you prefer to keep the depth of hole equal to the height of calibrating cylinder ?
22. What modification would you like to make to your sand replacement method if it is used in soils having boulders and stones ?
23. What is hand scoop method to determine the in-place density of soils ?

DISCUSSIONS

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

TABLE 1

Soil Sample No.

(Core Cutter Method)

Date

Internal diamer of cutter (cm) =
Height of cutter (cm) =
Cross-sectional area of cutter (cm^2) =
Volume of cutter, V (cm^3) =
Specific gravity of soil, G_s =
(measured or given or assumed)

Determination No.		1	2	3
(1) Mass of core cutter, W_1	(gm)			
(2) Mass of cutter + soil, W_2	(gm)			
(3) Mass of wet soil, (W_2-W_1)	(gm)			
(4 Moisture content crucible No.				
(5) Mass of crucible	(gm)			
(6) Mass of crucible + wet soil	(gm)			
(7) Mass of crucible + dry soil	(gm)			
(8) Mass of water = (6) − (7)	(gm)			
(9) Mass of dry soil = (7) − (5)	(gm)			
(10) Moisture content, $w = \frac{(8)}{(9)} \times 100$				
Results				
(11) Wet density $\gamma_t = \frac{W_2-W_1}{V}$	(g/cm^3)			
(12) Dry density $\gamma_d = \frac{\gamma_t}{1+w}$	(g/cm^3)			
(13) Void ratio, $e = \frac{G_s \gamma_w}{\gamma}$				
(14) Degree of saturation, $S = \frac{wG_s}{e} \times 100$	(%)			

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

TABLE 2

Calibration of Apparatus

Soil Sample No. Date

Determination No.		1	2
(1) Volume of calibrating container, V	(ml)		
(2) Mass of pouring cylinder + sand, W_1' (Before pouring in the calibrating cylinder)	(gm)		
(3) Mass of pouring cylinder + sand, W_2' (After pouring in the calibrating cylinder)	(gm)		
(4) Mass of pouring cylinder + sand, W_3' (Afer making the sand cone on a flat surface)	(gm)		
(5) Mass of sand for filling the calibrating cylinder and cone, $W_4' = (W_1' - W_2')$	(gm)		
(6) Mass of sand for making the cone only, $W_5' = (W_2' - W_3')$	(gm)		
(7) Mass of sand in the calibrating cylinder only, $W_6' = (W_4' - W_5')$	(gm)		
(8) Bulk density of sand, $\gamma_b = \frac{W_6'}{V}$	(g/cm³)		

TABLE 3

(Sand Replacement Method)

Soil Sample No. Date

Water Content Determination of Excavated Soil

Determination No.		1	2	3
(1) Crucible No.				
(2) Mass of crucible + wet soil, W_1	(gm)			
(3) Mass of crucible + dry soil, W_2	(gm)			
(4) Mass of crucible W_3	(gm)			
(5) Mass of water, $W_w = W_1 - W_2$	(gm)			
(6) Mass of dry soil, $W_d = W_2 - W_3$	(gm)			
(7) Water content, $w = \frac{W_w}{W_d} \times 100$	(%)			

EXPERIMENT No. 11

IN-PLACE DENSITY

OBSERVATIONS AND CALCULATIONS

Soil Sample No.

TABLE 4

Date

Specific gravity of soil solids (given or assumed), G_s =

Determination No.		1	2	3
(1) Mass of pouring cylinder + sand, W_1 (Before pouring in the hole)	(gm)			
(2) Mass of pouring cylinder + sand, W_2 (After pouring in the hole)	(gm)			
(3) Mass of pouring cylinder + sand, W_3 (After making sand cone on a flat surface)	(gm)			
(4) Mass of sand used in the hole and cone, ($W_4 = W_1 - W_2$)	(gm)			
(5) Mass of sand in the cone only ($W_5 = W_2 - W_3$)	(gm)			
(6) Mass of sand in the hole only ($W_6 = W_4 - W_5$)	(gm)			
(7) Volume of sand, $V = \frac{W_6}{\gamma_b}$ (from table 2) (equal to volume of hole)	(cc)			
(8) Mass of tray + excavated soil, W_7	(gm)			
(9) Mass of tray only, W_8	(gm)			
(10) Mass of excavated soil ($W = W_7 - W_8$)	(gm)			
Results				
(11) Wet density of soil $\gamma_t = \frac{W}{V} = \frac{(10)}{(7)}$	(g/cm³)			
(12) Dry density, $\gamma_d = \frac{\gamma_t}{1+w}$	(g/m³)			
(13) Void ratio, $e = \frac{G_s \gamma_w}{\gamma_d} - 1$				
(14) Degree of saturation $S = \frac{w\, G_s}{e} \times 100$	(%)			

Note : w is taken from table 3 and is put in decimals